On Some Possibilities of Organizing a Mobile Hardware-information System for Polyfactorial Neuro-electrostimulation

Vladimir Kublanov, Mikhail Babich and Anton Dolganov
Research Medical and Biological Engineering Centre of High Technologies, Ural Federal University, Mira 19, 620002, Yekaterinburg, Russian Federation

Keywords: Neuro-electrostimulator, Current Pulses Field, Neuroplasticity, Information System, Machine Learning.

Abstract: In paper the organizational principles of the mobile hardware-information system for polyfactorial neuro-electrostimulation were considered. It was shown that the system can be implemented by three functionally separate blocks, one of which ensures the formation of a spatially distributed field of current pulses, the second is the specialized interface for the patient, and the third is the specialized interface for the doctor. The exchange of information between the blocks is provided by a telemetric communication channel or via the global network using mobile wearable computers (which can include a personal computer, tablet or smartphone). A personalized patient information system can be implemented on the basis of the neuro-electrostimulation system. In this case patient data can be placed on the server of the medical institution. The prospects for using artificial intelligence and machine learning to control the treatment process were discussed.

1 INTRODUCTION

Medical rehabilitation today is the relevant area of medicine, which is associated with its great social significance (Gunn, 2017; Khan et al., 2015; Voinea et al., 2017).

It is known that the state of health and illness differ in the level of the adaptive mechanisms in the body (Pulakat et al., 2011). Increasing the adaptation of a healthy person to constantly changing environmental conditions is the main measure of health and is achieved through temporal adjustment. Adaptation of a sick person to the conditions of existence is carried out by compensating for impaired functions. At the same time, adaptation and compensatory mechanisms are based on functional, biochemical and morphological properties and reactions of the body that are similar in nature and are based on increasing of the functional capabilities for existing structures and functions (Ram-Tiktin, 2011).

In order to launch these mechanisms, particular conditions are necessary that can be initialized with the help of biotechnical systems of restorative medicine, in which physical fields are used for stimulation. At the same time regulatory systems that stimulate the processes of adaptation and compensation are used as stimuli targets.

This article discusses some of the possibilities for organizing such system in which polyfactorial neuro-electrostimulation is used to control the processes of adaptation and compensation.

2 MATERIALS AND METHODS

Stimulation of the Neck Neural Formations and Organization of the Neuro-electrostimulation Process Management

In general, modern biotechnical systems, which are focused on solving the problems of medical rehabilitation, should provide:

1. Formation in the problem area of the body by means of the external physical field for targeted physiological changes aimed at restoring the health of persons with disabilities.

2. Regulation of the structure of the external physical field and its biotropic parameters, as well as the choice of targets for stimulation, which form the 'targeted' physiological changes.

Kublanov, V., Babich, M. and Dolganov, A.
On Some Possibilities of Organizing a Mobile Hardware-information System for Polyfactorial Neuro-electrostimulation.
DOI: 10.5220/0007695505720576
In *Proceedings of the 12th International Joint Conference on Biomedical Engineering Systems and Technologies (BIOSTEC 2019)*, pages 572-576
ISBN: 978-989-758-353-7

3. Measuring the patient's response to targeted stimulation by monitoring functional changes in the central and autonomic nervous systems, as well as mental and behavioral functions.

With that in mind, the first task is conditionally “tied” to the patient, the second to the doctor. To implement the third task, one can use both embedded and stationary systems of functional diagnostics. Recently, video surveillance systems are also in high demand (Klompmaker et al., 2010).

An individual multidisciplinary approach to medical rehabilitation organization is promising. The physician must take into account the patient's age, gender, main and concomitant diseases, the degree of adaptation-compensatory mechanisms training and the biorhythmic activity of the vital body functions. This means that during rehabilitation, data on clinical, functional and mental changes should be observed during the treatment process. Using this data allows physician to organize an information system to support the treatment process.

According to WHO, impaired cerebral circulation and diseases for which treatment requires neurorehabilitation are the most common causes of disability and mortality among the population (WHO, 2018). As noted earlier in our papers (Kublanov, 2008), technologies that use a spatially distributed field of monopolar low-frequency current pulses, which characteristics are similar to endogenous processes in neural networks, are promising for solving such rehabilitation problems. In this case, neural formations of the neck are used as targets for stimulation: segmental control centers of vital functions (cervical sympathetic ganglia) and pathways of suprasegmental homeostasis regulation centers (glossopharyngeal and vagus nerves and their branches, as well as the cervical plexus of spinal nerves).

At the same time, during the electrical stimulation of the cervical spinal plexus, branches of the vagus, accessory and glossopharyngeal nerves, the gray matter of the brainstem can be stimulated along afferent pathways. Through the reticular formation, the effect in this case extends to the thalamic structures and the cerebral cortex. Stimulation of the sympathetic trunk nodes provides an effect on both the vascular tone of the cerebral arteries and the vegetative nuclei of the spinal cord. As a result of these actions, it is possible to influence various functional processes in the brain tissues, modulate the autonomic processes, and influence the motor control and cognitive functions (Michailov et al., 2013).

An analysis of the anatomical features for the neural formations in the neck made it possible to establish that, for neuro-electrostimulation tasks, 6 targets on the neck surface are promising, the projections of which correspond to the location of the upper and middle cervical ganglia of the sympathetic nervous system (target 1), the sympathetic trunk (target 3)), spinal plexus (target 4), vagus nerve (target 5), accessory nerve and branches of the glossopharyngeal nerve (target 6) (Orlov and Nozdrachev, 2010).

The formation of these stimulation targets is ensured by selecting the electrodes of a neuro-electrostimulator, which allow the formation of an adequate field of current pulses in the projection of the corresponding nervous formations. Example of the electrodes formation, which allows stimulation of the aforementioned targets is presented on Figure 1.

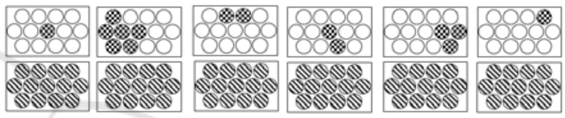

Figure 1: Electrodes combinations for different targets.

Living organisms are complex and consist of many interconnected systems, its functional state is determined by a large number of biophysical variables (factors). The more factors that can be used in rehabilitation, the more likely it will be to achieve the desired therapeutic effect. In addition, each of the methods used in rehabilitation should complement and not duplicate the others, be independent of them and not create discomfort due to the inconvenience of operation. Therefore, a promising neuro-electrostimulator should, on the one hand, be polyfactorial, and on the other, be compact and mobile, since the large mass-dimensional characteristics of the neuro-electrostimulator may be the reason for the discomfort.

3 RESULTS

Organization of Hardware-information System

Based on the tasks to be solved, the neuro-electrostimulator of the mobile hardware-information system can be implemented from three functionally separate blocks:

• the first block ensures the formation of a monopolar rectangular current pulses field;

• the second block is a specialized patient interface and provides a solution of two tasks:
- changing the structure of current pulses the field, setting the values of biotropic parameters of pulses (amplitude, duration and repetition rate of a sequence of consecutive pulses) and choosing the stimulation target;
- collecting information about the patient, its clinical data and functional parameters of the central and autonomic nervous systems, as well as monitoring data for the neurorehabilitation process;

• the third block is a specialized doctor interface and provides:
- data input into the second block on the structure of the current pulse field, the value of the biotropic parameters of the pulses and the stimulation target;
- provides the second block with data for managing the treatment process (turning on / off the first block and parameters of the cyclogram of the stimulation procedure), as well as comments about the patient and the course of the treatment process.

The schematic of the mobile hardware-information system for the polyfactorial neuro-electrostimulation is presented on Figure 2.

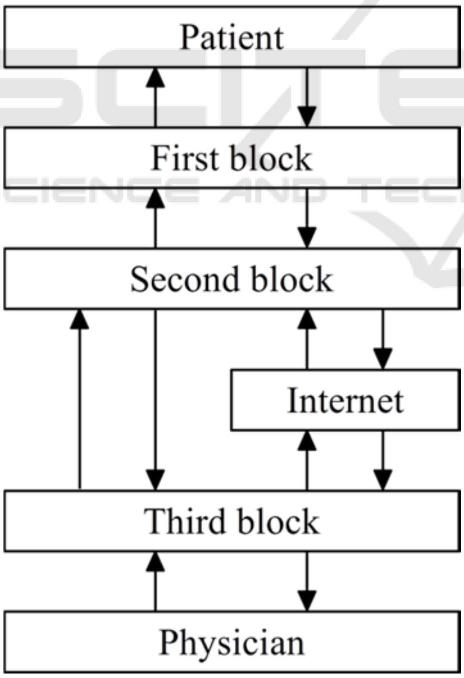

Figure 2: Mobile hardware-information system schematic.

In order to ensure the mobility and compactness of the first block, in its implementation it is necessary to use high-level system integration electronic radio devices and microcontrollers. It consists of two multi-element electrodes, between which a spatially distributed field of current pulses is formed; a multichannel source of pulsed current, the functions of which are realized by two multiplexers and a controlled current source; battery; transceiver telemetry communication channel; flash memory that implements the functions of a persistent storage device; microcontroller. Flash memory allows physician to save individual patient data, as well as data on the structure of the field of current pulses and the characteristics of partial pulses in each treatment procedure. It is essentially one of the main carriers of information about the patient’s treatment process, provides the ability to use its personalized medicine system and save these data in the service available for global computer networks. The technical implementation of the first unit made it possible to ensure its compactness and mobility: the prototype of the product has a mass of not more than 200 g, and its overall dimensions are 90x50x18 mm.

Mobile wearable computers can be used as the second and third units, which include a personal computer, tablet or a smartphone. The exchange of information between the first and second blocks is provided by a telemetric communication channel (in particular Bluetooth Low Energy), and between the second and third blocks via the Internet.

With the help of wearable computers, it is possible to organize the interaction of a doctor and a patient remotely using telemedicine technical means via the Internet.

The approach described above made it possible to implement a system for neuro-electrostimulation using mobile and compact devices.

4 DISCUSSION

Information System of the Treatment Process Support in Neurorehabilitation

The information support system for the treatment process should be formed using personalized data from patients who have undergone a course of neurorehabilitation. In general, regardless of the pathology that is treated during medical rehabilitation, for the implementation of such a system it is necessary to solve the following tasks:
1. The choice of biomedical signal, which is a reliable indicator of changes in the functioning of the patient's state in case of particular pathology.
2. Determination of the diagnostically significant features complexes for this biomedical signal to assess the current functional state of the patient.

3. Prediction of the functional state for the patient during the treatment process.

Let us consider a case study of information support for the treatment process using the example of developing a decision support system for a physician in the treatment of arterial hypertension.

Analysis of the pathophysiological factors of arterial hypertension indicates a special role of the autonomic nervous system in their formation (da Silva et al., 2014). It is known that blood pressure is supported by physiologically several regulatory mechanisms, including neuronal and humoral. The exclusive role here belongs to the vegetative nervous system. Therefore, its functional disorders can be considered as the most important pathophysiological factor in the development of arterial hypertension. For example, in the pathogenesis of hypertension, the role of increased activity of the sympathetic division of the autonomic nervous system is noted, which can lead to impaired neurogenic regulation of the circulatory system (Cardinali, 2017).

The works of physiologists have shown that heart rate variability (HRV) can be a reliable indicator of changes in the autonomic nervous system (Malik, 1996). The HRV reflects the work of the cardiovascular system and mechanisms of regulation of the whole organism, including the overall activity of regulatory mechanisms, neuro-humoral regulation of the heart, the relationship between the sympathetic and parasympathetic divisions of the autonomic nervous system.

To reduce the effect of situational deviations on the results of diagnostics, it is advisable to use functional tests (or loads) in studies. In this case, when choosing the load that activates the reaction of the problem function, one can get information that most fully reflects the pathophysiological state of the patient. In case of the cardiovascular system disorders rehabilitation, a tilt-test study is often used as such a load, in which the patient is transferred from a horizontal position to vertical head up and back to horizontal position.

The study involved two groups of subjects - relatively healthy volunteers and patients suffering from arterial hypertension of 2-3 degrees (Dolganov et al., 2017). It is known that the HRV signal can be described by a variety of features in the time and frequency domains, as well as using nonlinear dynamics methods. After reduction of the HRV features numbers, it is possible to form a sets of diagnostically significant features using the methods of machine learning in solving the problem of binary classification. The best solution was obtained using a search strategy based on evolutionary programming. In that case, quadratic discriminant analysis was used as a classification method. The obtained sets of diagnostically significant features consisted of 12–15 features of HRV (out of 192 features total) recorded in each of the functional states when performing tilt-test studies:

If one apply quadratic discriminant analysis to predict the class of the subject ("healthy" or "patient suffering from arterial hypertension"), then the result of this operation will be the intended class of the subject and the probability of belonging to this class. As there are only two classes of subjects, the use of quadratic discriminant analysis allows to reduce the multidimensional space of diagnostically significant parameters to the one-dimensional space of the decision rule metrics. When training a classifier, a hyperplane is formed that separates the two classes of subjects. In the decision rule space, this hyperplane defines the origin. In our case, the positive values of the metric in the space of decision rules correspond to the class of subjects "healthy", the negative values of the metric correspond to the class of subjects "patients suffering from arterial hypertension". In our case the accuracy of the proposed approach can reach 98% (Dolganov and Kublanov, 2018).

Further, changes in the metrics in the space of decision rules and the dynamics of changes in blood pressure during the treatment process were analyzed. It was shown that the dynamics of changes in the metrics obtained on the basis of sets of diagnostically significant features had a rather high degree of consistency with changes in blood pressure. This indicates that the obtained sets of diagnostically significant features can be used as additional markers of change during the rehabilitation process.

5 CONCLUSION

The organization principles of the hardware-information system proposed in this work allowed to create a mobile and compact system for neurorehabilitation. It was shown that the application of artificial intelligence and machine learning makes it possible to ensure the management of the rehabilitation process taking into account the requirements of personalized medicine.

At the moment, the neuro-electrorehabilitation polyfactorial system has been clinically tested in the treatment of depressive anxiety disorders, children with attention deficit disorder, rehabilitation of patients after traumatic brain injuries (Kublanov, Retyunskii, et al., 2016; Kublanov, Petrenko, et al., 2016; Kublanov et al., 2017; Petrenko et al., 2015, 2017). Clinical studies have shown that, compared with the state-of-art, a higher efficiency of treatment is achieved by involving the regulatory process in addition to the autonomic nervous system, brain structures responsible for cognitive, motor, visual, auditory, vestibular and other brain functions. Finally, the rehabilitation process is becoming more adapted to the problems of a particular patient.

ACKNOWLEDGEMENTS

The work was supported by Act 211 Government of the Russian Federation, contract № 02.A03.21.0006.

REFERENCES

Cardinali DP (2017) *Autonomic Nervous System: Basic and Clinical Aspects*. Springer.

da Silva NT, Giacon TR, Vanderlei FM, et al. (2014) Hypertension and Autonomic Control. *American Journal of Medical Sciences and Medicine* 2(2): 48–53.

Dolganov A and Kublanov V (2018) Towards a Decision Support System for Disorders of the Cardiovascular System - Diagnosing and Evaluation of the Treatment Efficiency. In: *Proceedings of the 11th International Joint Conference on Biomedical Engineering Systems and Technologies - Volume 5: AI4Health (BIOSTEC 2018)*, 22 May 2018, pp. 727–733. DOI: 10.5220/0006753407270733.

Dolganov AY, Kublanov VS, Belo D, et al. (2017) Comparison of Machine Learning Methods for the Arterial Hypertension Diagnostics. *Applied Bionics and Biomechanics* 2017(5985479). DOI: 10.1155/2017/5985479.

Gunn AE (2017) Cancer rehabilitation. *Phys Med Rehabil Clin N Am* 28(1): 1–17.

Khan F, Amatya B, Gosney J, et al. (2015) Medical rehabilitation in natural disasters: a review. *Archives of physical medicine and rehabilitation* 96(9): 1709–1727.

Klompmaker F, Busch C, Nebe K, et al. (2010) Designing a Telemedical System for Cardiac Exercise Rehabilitation. In: *Biomedical Engineering Systems and Technologies*, 20 January 2010, pp. 111–122. Communications in Computer and Information Science. Springer, Berlin, Heidelberg. DOI: 10.1007/978-3-642-18472-7_9.

Kublanov V, Dolganov A, Shalyagin M, et al. (2017) Efficiency of dynamic correction of sympathetic nervous system activity in patients with panic disorder. In: *Proceedings - 2017 International Multi-Conference on Engineering, Computer and Information Sciences, SIBIRCON 2017*, Novosibirsk Akademgorodok, Russia, 2017, pp. 571–574. DOI: 10.1109/SIBIRCON.2017.8109956.

Kublanov VS (2008) A hardware-software system for diagnosis and correction of autonomic dysfunctions. *Biomedical Engineering* 42(4): 206–212. DOI: 10.1007/s10527-008-9047-7.

Kublanov VS, Retyunskii KY and Petrenko TS (2016) A New Method for the Treatment of Korsakoff's (amnestic) Psychosis: Neurostimulation Correction of the Sympathetic Nervous System. *Neuroscience and Behavioral Physiology* 46(7): 748–753.

Kublanov VS, Petrenko TS, Petrenko AA, et al. (2016) The recovery of cognitive functions for patients with the organic amnestic syndrome by means of the non-invasive adaptive neuro-electrostimulation device. In: *Cognitive Sciences, Genomics and Bioinformatics (CSGB)*, 2016, pp. 1–3. IEEE.

Malik M (1996) Heart rate variability: Standards of measurement, physiological interpretation, and clinical use. *Circulation* 93(5): 1043–1065.

Michailov SS, Chukbar AV and Tsybul'kin AG (2013) *Human Anatomy [in Russian]*. M.: GEOTAR-Media.

Orlov RS and Nozdrachev AD (2010) *Normal Physiology. A. Textbook [in Russian]*. M.: GEOTAR-Media.

Petrenko T, Kublanov V and Retyunskiy K (2017) The role of neuroplasticity in the treatment of cognitive impairments by means multifactor neuro-electrostimulation of the segmental level of the autonomic nervous system. *European Psychiatry* 41: S770.

Petrenko TS, Kublanov VS and Retiunskiy KY (2015) Dynamic Correction of the Activity Sympathetic Nervous System (Dcasns) to Restore Cognitive Functions. *European Psychiatry* 30: 843.

Pulakat L, DeMarco VG, Ardhanari S, et al. (2011) Adaptive mechanisms to compensate for overnutrition-induced cardiovascular abnormalities. *American Journal of Physiology-Regulatory, Integrative and Comparative Physiology* 301(4): R885–R895.

Ram-Tiktin E (2011) A decent minimum for everyone as a sufficiency of basic human functional capabilities. *The American Journal of Bioethics* 11(7): 24–25.

Voinea G-D, Butnariu S and Mogan G (2017) Measurement and geometric modelling of human spine posture for medical rehabilitation purposes using a wearable monitoring system based on inertial sensors. *Sensors* 17(1): 3.

WHO (2018) *World Health Statistics 2018: Monitoring Health for the SDGs Sustainable Development Goals*. World Health Organization.